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Modeling fuel consumption in various external vehicle conditions for military vehicle using mixed linear models

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Abstract

With the crisis in fuel consumption, it is necessary to save fuel consumption by selecting fuel that is quite efficient. The aim of this research is to examine the fuel consumption patterns of vehicles in an area that experiences external vehicle conditions and various weathers. In this research, the data used were secondary data such as speed, distance, temperature, and weather. In this case, the main response is the gas type, both type E10 and SP98, which is a comparison in its effect on the effectiveness of car fuel consumption. Data collection was carried out in certain weather, namely sunny, rainy, and snowy, thus affecting the outside temperature as well. Using the linear mixed effect model, and the anova (analysis of variance) mathematical model, the results of the analysis state that different types of fuel have a very significant effect in influencing the fuel consumption of a vehicle. Based on modeling results, it also can be identified that fuel consumption is strongly influenced by the type of fuel used by the vehicle. Meanwhile, other variables such as vehicle mileage, average speed, and ambient temperature at the time did not show any significant effect on fuel consumption

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INTRODUCTION

Energy is an important factor in achieving goals and programs in a country. One of the energy that is always used is sourced from the fossil earth, namely petroleum or fuel oil. Fuel is used in almost every sector in the country to meet people's needs. Every year the need for fuel has increased higher and higher due to technological developments. The oil and gas industry is an important industry for national development, and to meet the energy and raw material needs of the country's industry, as well as generate foreign exchange for the country, its management must be managed as optimally as possible. Endeavor to realize an oil and gas business that is independent, reliable, transparent, competitive, efficient by taking into account the preservation of environmental functions and the development of national potential and role that can support the sustainability of national development.

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Indonesia is the country with the largest energy consumption in Southeast Asia and fifth in Asia Pacific in primary energy consumption, after China, India, Japan and South Korea with primary energy consumption of 185.5 MTOE in 2018. (Afriyanti Y et al., 2020) According to the Director General of New, Renewable Energy and Energy Conversion (EBTKE) of the Ministry of Energy and Mineral Resources (2018), fossil energy reserves are increasingly depleting. The data shows that the current coal reserves are around 7.3-8.3 billion tons which are predicted to be used up in 2026. Meanwhile, the current oil stocks of 3.7 billion barrels are predicted to be used up in 2028.

The transportation sector is the largest fuel consumption sector among other sectors. According to a study conducted by the Ministry of Transportation, the land transportation sub-sector consumes around 80% of all fuel consumed by the transportation sector. Meanwhile, the air transportation, sea transportation and ASDP sectors use international standard facilities, so consumption in this sub-sector is considered to have achieved reasonable efficiency. (Abdulkadir, 2000)

Several factors affect the consumption of fuel oil energy in Indonesia, including economic growth, population growth, energy subsidies, and consumption of fossil energy. Consumers who use gasoline complain that gasoline-powered cars often experience knocking when using unleaded gasoline compared to unleaded gasoline. Engine knocking leads to unnecessary fuel consumption and increases exhaust emissions. One of the possible causes of knocking, especially at high loads, is that the engine octane number (MON) of the gasoline is much lower than the research octane number (RON). Usually, the RON value is larger than the MON, and the difference between the two values (RON - MON) is called sensitivity. It represents the sensitivity of the fuel to change under severe operating conditions from an anti-knock perspective (Djainuddin S., 2008).

In the field of defense, the presence of formidable military vehicles is indispensable. One form of toughness is not only about the strength of the structure, but can also talk about the effective use of fuel. Therefore, we need a way to regulate fuel consumption for vehicles, especially military vehicles. One of the factors that can be controlled in managing fuel oil is by choosing which fuel oil is right for consumption so as to reduce the occurrence of an energy deficit. This is one step for the government in an effort to reduce the use of fossil energy, especially fuel oil. The purpose of this research is to examine the fuel consumption pattern of vehicles in an area that experiences several weathers so that it can determine the level of efficiency of fuel used.

METHODS

This research method is qualitative, based on experimental data conducted by Andreas Wagener in the United States which began in November 2018. The experiment was conducted to determine the influence of several factors on fuel consumption in car vehicles, both from factors such as fuel type, distance, speed, and temperature, to weather. To determine the influence of these factors on car fuel consumption, a test was carried out using linear model techniques, the linear mixed effect model, and anova mathematical model (Pinherio & Bates, 2004; Aisyah et al, 2023).

Linear model commonly used to identify subclasses of models that allow substantial complexity of related statistical theories. Meanwhile, linear mixed model is the result of the development of a linear model where the response variable (Y) is influenced by fixed effects and random effects. A fixed effect is an explanatory variable while random effects can be explained using time, area, and other influences. Two-way anova is also called 2-way anova compares the mean differences between groups that have been divided into two independent variables (called factors).

In the study, the data used were secondary data such as speed, distance, temperature, and weather. In this case, the main reference is the gas type, both type E10 and SP98, which is a comparison in its effect on the effectiveness of car fuel consumption. Gas Type E10 is a type of fuel mixture between gasoline and ethanol as much as 10%. E10 is widely used in the United States, so the presence of this fuel is difficult to find in some countries. By and large, E10 gas is a fuel used in lawnmowers with a composition of 10% ethanol and 90% gasoline. (Wagener, 2018). Gas Type SP98 is a type of super plus gasoline that has a higher octane than E10 so the selling price is more expensive. Higher octane gasoline such as SP98 gasoline will have better crackling resistance and hence better combustion (controlled). In addition, the WHO says clean machines say optimization of consumption and, consequently, reduction of pollution (Gino, 2019).

In the experiment, data collection was carried out in certain weather, namely sunny, rainy, and snowy, thus affecting the outside temperature as well. When weathering, the temperature produced is greater than in rainy and snowy weather. In addition, data collection was carried out using a speed of about ≤90 km / h with mileage in each experiment from the range of 4.9 – 28 km, but at a certain time the mileage taken was constant at ± 12 km.

RESULTS AND DISCUSSION

Analysis of Models

In this study, several mathematical modeling was carried out to measure the level of significance of several types of variables that exist for an outcome, namely fuel consumption in vehicles. Several forms of models are used as shown in Table 1.

Table 1. Several forms of model

Model	Variable				
	Fuel type	Weather	Speed	Distance	Temp Outside
1			V	V	
2	V				
3	V		V	V	V
4		V	V	V	
5		V			V
6	V	V			
7	V	V	V	V	
8	V	V			V
9	V	V	V	V	V

In the first stage, we need to identify several variables that may have a high influence on the level of vehicle fuel consumption. We model this in the form of a mathematical equation which will be solved by a linear mixed model without random effects. In looking at the relationship of speed and distance to the effect of fuel consumption using the first model as follows,

$$Y_{ijk} = \beta_0 + \beta_1 t_k + \varepsilon_{ijk} \quad (1)$$
$$\varepsilon_{ijk} \sim N(0, \sigma^2_{res})$$

Where fuel consumption is expressed as Y_{ijk} and ε_{ijk} is the residue of the output variable for the fuel consumption of a vehicle. This model illustrates that there is no significant effect of the distance traveled by the car and the average speed driven on the fuel consumption of the car. This is evidenced by the p-value of speed and distance which is greater than the specified significance level

(α = 0.05). Furthermore, a search for variables that affect fuel consumption is carried out by linking the type of fuel used to model 2.

$$Y_{ij} = \beta_0 + \beta_1 t_j + \varepsilon_{ij} \quad (2)$$
$$\varepsilon_{ij} \sim N(0, \sigma^2_{res})$$

Model 2 displays the effect of the type of fuel used on fuel consumption in the car used. The results of the p-value on the type of fuel show that the type of fuel has a significant effect on fuel consumption. This is indicated by the p-value which is close to 0, far from the established significance level. From the two models that have been tested using the linear mixed model, it is revealed that only the type of fuel has a significant effect on fuel consumption when compared to the average speed and distance traveled by the test car. The complete results of the linear mixed model significance model in model 1 and model 2 are presented in Table 2.

Table 2. The results of the Linear Mixed Model significance model

Model	Variable	Value	std Error	p-value
1	(Intercept)	5,3993	0,0961	0,0000***
	speed	-0,0001	0,0009	0,9040
	distance	-0,0074	0,0074	0,3180
2	(Intercept)	5,2184	0,0187	0,0000***
	gas type	0,1538	0,0244	0,0000***

***significance at $\alpha = 1\%$

To further prove the significance of the effect between variables on fuel consumption, the existing variables were re-modeled using an analysis of variance (anova) approach. With this approach, the condition of the distance traveled, the average speed of the car, and the ambient temperature will be modeled in a mathematical equation to determine the level of significance of the effect on fuel consumption. The ambient temperature variable is added to determine the relationship between high and low ambient temperatures around the car affecting engine performance which results in the level of fuel consumption also having an effect. This model 3 equation is described as

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk} \quad (3)$$
$$\varepsilon_{ijk} \sim N(0, \sigma^2_{res})$$

From the results of the modeling carried out and presented in Table 3, it can be explained that in model 3 itself the type of fuel still has a very high level of significance in influencing the fuel consumption of the cars used. This is in contrast to the other variables included in model 3 such as distance traveled, average speed and ambient temperature which do not have a significant effect on high fuel consumption. This is in accordance with the modeling results of the 2 previous models using the linear mixed model. This means that the type of fuel has more influence when compared to mileage, average speed, ambient temperature using the ANOVA method.

Table 3. The results of the ANOVA significance model

Model	Variable	Sum sq	Mean Sq	p-value
3	Gas type	2,2241	2,22406	0,000***
	Distance	0,0206	0,0206	0,546
	Speed	0,0138	0,0138	0,6212
	Temp outside	0,057	0,0569	0,3158
	Residuals	21,6297	0,0564	

***significance at $\alpha = 1\%$

The next stage is to prove again that the variable type of fuel affects the fuel consumption of a vehicle using another method, namely the linear mixed model with random effects. We use weather condition variables as the effect of random variables in this form of modeling. This is expected to prove the effects of other variables such as mileage, speed and ambient temperature on fuel consumption with the influence of weather as an additional random variable. First, we re-model the effect of distance traveled and average speed on fuel consumption through model 4. Model 4 can be written into an equation as follows,

$$Y_{ij} = \beta_0 + \beta_1 t_j + \beta_2 X_1 + \beta_3 X_2 + \alpha_i + \varepsilon_{ij} \quad (4)$$
$$\alpha_i \sim N(0, \sigma^2_{state}),\ \varepsilon_{ij} \sim N(0, \sigma^2_{res})$$

From the results of the significance presented in table 4, the p-value of speed and distance is greater than the predetermined significance level. This indicates that by using the linear mixed model, speed and distance do not have a significant high level of influence on fuel consumption. Then re-modeled the significance of each fuel consumption to the influence of ambient temperature and the type of fuel used. This model is represented by model 5 and model 6 respectively. With this, we can see the effect of each independent variable on fuel consumption with the random effect of weather conditions when the data is collected. Further equations of these models are,

$$Y_{ij} = \beta_0 + \beta_1 t_j + \beta_2 X_1 + \alpha_i + \varepsilon_{ij} \quad (5)$$
$$\alpha_i \sim N(0, \sigma^2_{state}),\ \varepsilon_{ij} \sim N(0, \sigma^2_{res})$$

The results of the significance of the two models show that the ambient temperature has a p-value greater than the predetermined significance level. So that the ambient temperature does not have a significant enough effect on vehicle fuel consumption even though there is only one independent variable in one model and the influence of weather is added as a random variable. However, under the same conditions, the different types of fuel used have a significant effect on fuel consumption. This can be seen in the p-value of the type of fuel in Table 4, the results of model 6. The p-value is lower than the significance level. Thus, differences in fuel types consistently have a significant effect on fuel consumption.

Table 4. The results of the Linear Mixed Model with random effect significance model

Model	Variable	Value	std Error	p-value
4	(Intercept)	5,3993	0,096	0,0000***
	speed	-0,0001	0,0009	0,9038
	distance	-0,0074	0,0074	0,3179
5	(Intercept)	5,3095	0,0241	0,0000***
	temp outside	0	0,0018	0,9713
6	(Intercept)	5,2184	0,0187	0,0000***
	gas type	0,1538	0,0244	0,0000***

***significance at $\alpha = 1\%$

If previously only shown the results of the model where the type of fuel is the only independent variable in the mathematical model compiled, then the next model will be tried to combine the independent variable type of fuel with other independent variables on fuel consumption with a linear mixed model approach with random effects. Weather conditions are still a random variable used to generate random effects on the models used. In model 7, the effect of average speed, distance traveled and type of fuel is modeled on fuel consumption. Model 7 uses the following equation

$$Y_{ij} = \beta_0 + \beta_1 t_j + \beta_2 X_1 + \beta_3 X_2 + \beta_4 X_3 + \alpha_i + \varepsilon_{ij} \quad (6)$$
$$\alpha_i \sim N(0, \sigma^2_{state}),\ \varepsilon_{ij} \sim N(0, \sigma^2_{res})$$

Furthermore, in model 8, fuel consumption is modeled by being influenced by the type of fuel and ambient temperature. The modeling equation used is as follows,

$$Y_{ij} = \beta_0 + \beta_1 t_j + \beta_2 X_1 + \beta_3 X_2 + \alpha_i + \varepsilon_{ij} \quad (7)$$
$$\alpha_i \sim N(0, \sigma^2_{state}),\ \varepsilon_{ij} \sim N(0, \sigma^2_{res})$$

The results of the significance of the two models above are presented in Table 5. Both show almost similar results where only the type of fuel has a high significance in influencing fuel consumption. The p-value of the type of fuel in both models is close to 0, so it is far from the significance level. While other variables such as speed and mileage in model 7 and ambient temperature in model 8 have no significant effect on fuel consumption.

Table 5. The results of the Linear Mixed Model with random effect significance model

Model	Variable	Value	std Error	p-value
7	(Intercept)	5,2479	0,0948	0,0000***
	speed	0,0004	0,0008	0,6212
	distance	-0,0042	0,0071	0,5574
	gas type	0,1539	0,0246	0,0000***
8	(Intercept)	5,2357	0,0257	0,0000***
	gas type	0,1574	0,0247	0,0000***
	temp outside	-0,0017	0,0017	0,3259

***significance at $\alpha = 1\%$

In model 9, modeling with more complex conditions will be carried out. Fuel consumption will be modeled by being influenced by all the independent variables in this data, namely ambient temperature, average speed, distance traveled and the type of fuel used. The completion of this modeling still uses a linear mixed model with random effects. Weather conditions remain a random variable in this mathematical model. The model equation 9 as follows,

$$Y_{ij} = \beta_0 + \beta_1 t_j + \beta_2 X_1 + \beta_3 X_2 + \beta_4 X_3 + \beta_5 X_4 + \alpha_i + \varepsilon_{ij} \quad (8)$$
$$\alpha_i \sim N(0, \sigma^2_{state}),\ \varepsilon_{ij} \sim N(0, \sigma^2_{res})$$

The results of the completion of model 9 are shown in **Table 6**. Similar to the results of the previous models, the difference in the type of fuel used has a high significance for fuel consumption. Other independent variables such as speed, distance traveled, and ambient temperature have a low significance for fuel consumption because the p-values of these three variables are above the significance level. The results of this model 9 strengthen the argument from the results of previous models where the type of fuel has a significant effect compared to the distance traveled, speed and ambient temperature on vehicle fuel consumption.

Table 6. The results of the Linear Mixed Model with random effect significance model

Model	Variable	Value	std Error	p-value
9	(Intercept)	5,2655	0,0964	0,0000***
	temp outside	-0,0017	0,0017	0,3157
	speed	0,0004	0,0008	0,6002
	gas type	0,1577	0,0249	0,0000***
	distance	-0,0042	0,0071	0,5499

***significance at $\alpha = 1\%$

Discussion

The results of the modeling analysis that has been carried out show that the different types of fuel have a very large significant effect in influencing the fuel consumption of a vehicle. From all the modeling that has been done with different approaches ranging from linear model, and linear mixed effect model, it shows that other independent variables such as average speed, mileage and ambient temperature do not have much effect on consumption fuel.

The influence of the type of fuel is very likely to occur due to differences in the octane number (RON) value for each type of fuel sold in the market. RON is the main value for the quality of fuel oil based on the size of the octane level. The higher the octane rating, the better the fuel is. The RON number simply shows how much pressure can be applied before the gasoline starts to burn in the vehicle's engine. The higher the RON value of a fuel, the more efficient the use of fuel in vehicles. The existence of this efficiency gives rise to differences in fuel consumption patterns in each type of gasoline (Budiharto, 2013).

Unlike the case with the distance traveled in this data collection deliberately takes almost the same distance data due to the similarity of the route passed. Mileage is not a significant influence on fuel consumption. This is because the level of consumption is measured in units of distance per volume of fuel used. Likewise with the average speed, because this model only uses average speed data in each data collection, we cannot see the fuel consumption pattern that is affected by it. Although according to Sindy Pangesty, there is a strong relationship between speed and vehicle fuel consumption, and there is a tendency that if speed increases, fuel consumption will also increase (Pangesty, 2021), this relationship cannot be seen in this model.

CONCLUSION

Based on the results of the modeling that has been done, it can be identified that the fuel consumption is strongly influenced by the type of fuel used by the vehicle. Meanwhile, other variables such as vehicle mileage, average speed, and ambient temperature at the time of data collection did not show any significant effect on fuel consumption. The influence of the type of fuel is possible because each type of fuel has a different octane number (RON). The higher the RON value of the fuel, the better the combustion produced by the fuel. Good or bad combustion will affect the efficiency of fuel consumption later.

For further research, it is necessary to investigate the effect of fuel type on vehicle type. This is because different types of engines should have different levels of fuel efficiency. Therefore, in addition to the use of different types of fuel, it is also necessary to know the correlation between the type of engine and the type of fuel.

AUTHOR CONTRIBUTIONS

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